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14. ABSTRACT Semiconductor nanowires have proven to be a viable path towards nanoscale photodetectors, however the dramatic reduction in semiconductor absorption volume can have a negative effect on responsivity. In order to overcome the reduced absorption volume, incident light must be focused within the nanopillar and surface reflections must be minimized. The ability to lithographically define the position and diameter of individual nanowires makes surface plasmon polariton (SPP) resonances an attractive option, as regular metal scattering centers can overcome the momentum mismatch between the incident wavevector and the SPP mode and scattering					
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Semiconductor nanowires have proven to be a viable path towards nanoscale photodetectors, however the dramatic reduction in semiconductor absorption volume can have a negative effect on responsivity. In order to overcome the reduced absorption volume, incident light must be focused within the nanopillar and surface reflections must be minimized. The ability to lithographically define the position and diameter of individual nanowires makes surface plasmon polariton (SPP) resonances an attractive option, as regular metal scattering centers can overcome the momentum mismatch between the incident wavevector and the SPP mode and scattering center size can influence optical absorption enhancement. In this work we demonstrate a 3-dimensional plasmonic antenna and show enhanced spectral response within the nanopillars.

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Reflection Spectromicroscopy for the Design of Nanopillar Optical Antenna Detectors

Alan C. Farrell¹, Pradeep Senanayake¹, Chung-Hong Hung¹, Marc Currie², and Diana L. Huffaker^{1,3}

¹ Electrical Engineering Department, University of California at Los Angeles, Los Angeles, CA 90095

² Optical Sciences Division, Naval Research Laboratory, Washington, DC 20375, USA

³ California NanoSystems Institute, University of California at Los Angeles, Los Angeles, CA 90095

Author e-mail address: acfarrell@ucla.edu

Semiconductor nanowires have proven to be a viable path towards nanoscale photodetectors [1], however the dramatic reduction in semiconductor absorption volume can have a negative effect on responsivity [2]. In order to overcome the reduced absorption volume, incident light must be focused within the nanopillar and surface reflections must be minimized. The ability to lithographically define the position and diameter of individual nanowires makes surface plasmon polariton (SPP) resonances an attractive option, as regular metal scattering centers can overcome the momentum mismatch between the incident wavevector and the SPP mode and scattering center size can influence optical absorption enhancement [3]. In this work we demonstrate a 3-dimensional plasmonic antenna and show enhanced spectral response within the nanopillars.

Uniform arrays of InGaAs nanopillars, shown in Fig. 1(a), were planarized by spin coating with bisbenzocyclobutene (CYCLOTENE, Dow Chemical) dry etch polymer and hard cured at 250°C for 60 minutes in a Carbolite high temperature oven. Vias for contact to the substrate were defined by photolithography and etched in an Oxford 80 Plus reactive ion etcher (RIE) with a 5:4 O₂/CF₄ gas mixture. Ohmic contact to the substrate was achieved by depositing germanium/nickel/germanium/gold (50 nm/100 nm/150 nm/200 nm) by electron-beam evaporation and thermal annealing at 380°C for 30 s. The nanopillar tips were subsequently exposed using RIE and top contacts were defined by photolithography. The exposed nanopillar tips were electrically contacted with chrome/gold (10 nm/150 nm) deposited with the substrate mounted at an angle, resulting in a self-aligned nanohole array (Fig. 1(b)). The photodetector active area is comprised of a 40 μm × 40 μm nanopillar array. Reflection spectrometry is a simple and effective tool for sensing surface plasmon resonances [4], and was used to characterize the 3-dimensional plasmonic antenna. The photodetector active area was illuminated by a synchrotron white light source which was focused to a 10 μm spot using a continuum IR microscope and the reflectance spectra was captured and analyzed with an FTIR-spectrometer. Fig. 1(a) shows the measured reflectance spectra for devices with pitches varying from 750 nm to 900 nm in 50 nm increments. A clear shift in the reflectance minimum to longer wavelengths is observable for increasing array pitch. In order to verify this reflection minimum is due to a plasmonic resonance and not to increased scattering outside the collection area of the objective, wavelength dependent photocurrent measurements were carried out using a supercontinuum white light source coupled to an acousto-optic tunable filter for wavelength selection. Fig. 2(b) shows the spectral photoresponse (the sharp drop near 1200 nm is due to the bandgap of InGaAs) and the corresponding reflectance spectrum. A peak in the photoresponse is readily observed at wavelengths near the reflection minimum, with a 67% reduction in reflectance resulting in a 51% increase in the photocurrent. Thus, 76% of the reduced reflection can be attributed to enhanced optical absorption in the nanopillar. Ohmic loss in the metal contact or surface recombination in the semiconductor likely accounts for the loss. Although the 3-dimensional plasmonic antenna is not symmetric, only a weak polarization dependence is observed (Fig. 2(c)). The reflectance spectrum is simulated by finite-difference-time-domain (FDTD) simulations of a single nanopillar unit cell with periodic boundary conditions. Although reflectance measurements were performed with focused light (range of incident angles), simulations were limited to a plane-wave source. As a result, the simulated reflectance spectrum shows more narrow, well defined reflectance dips (Fig. 3(a)). FDTD simulations of the plasmonic modes indicate the absorbed power density is located almost exclusively within the exposed nanopillar tips at resonance (Fig. 3(b)), while little power is absorbed in the pillars off resonance (Fig. 3(c)).

In conclusion, we have demonstrated a 3-dimensional plasmonic antenna structure defined by nanopillar geometry and metal deposition angle alone, without the need for expensive e-beam lithography or additional processing steps. The plasmonic antenna supports SPP modes at wavelengths defined by the array pitch resulting in enhanced optical absorption in the semiconductor nanopillar. Through additional antenna structure design—in terms of exposed pillar height, pillar diameter, and metal deposition angle—localized surface plasmon resonances can be tuned to the same wavelength as SPP modes and further enhance optical absorption.

4. References

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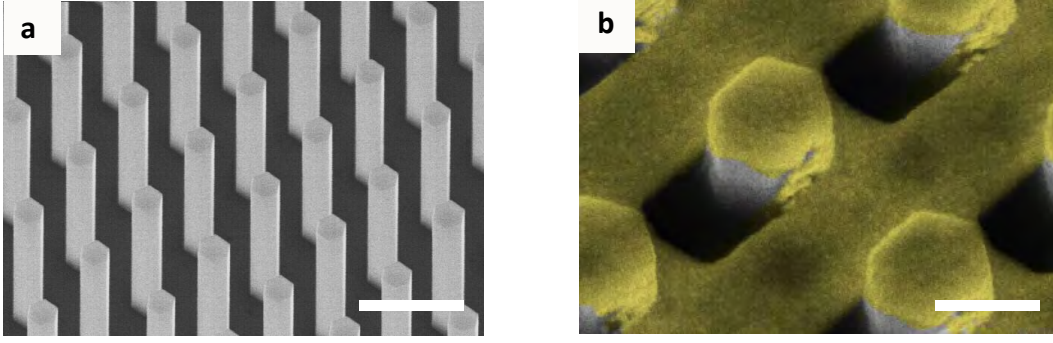


Fig. 1 (a) Tilted SEM of as-grown InGaAs nanopillar array. Scale bar, 600 nm. (b) Fabricated detector with self-aligned nanohole array fabricated through tilted metal deposition. Scale bar, 200 nm.

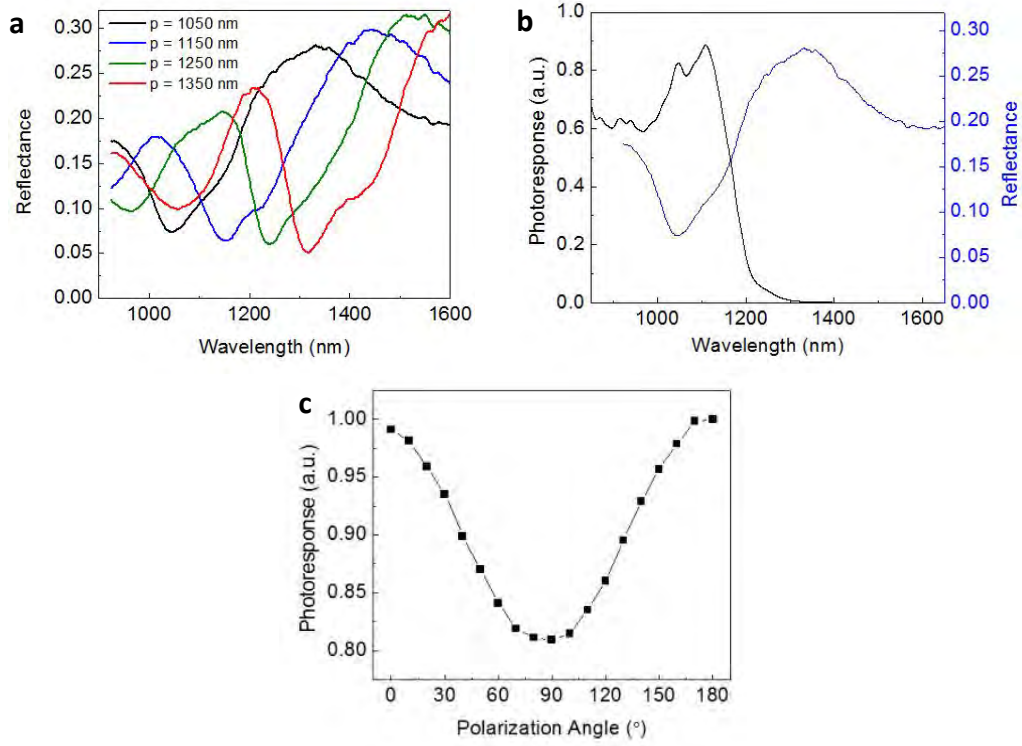


Fig. 2 (a) Plasmonic resonance can be shifted to longer wavelengths by increasing the nanopillar array pitch. (b) A minimum in the reflectance occurs at the same wavelength as a maximum in the photoresponse. (c) Photocurrent shows weak polarization dependence.

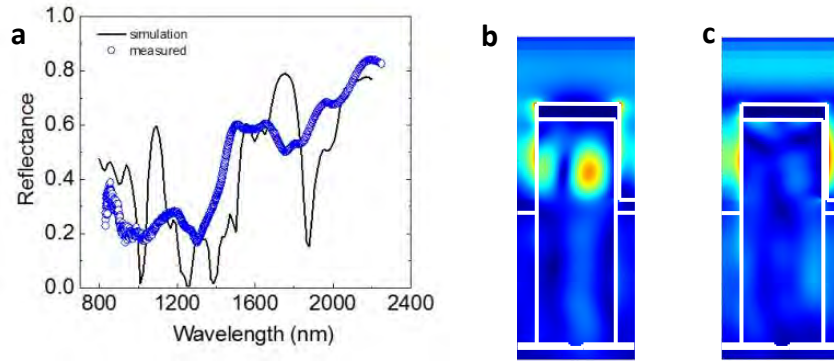


Fig. 3 (a) Measured (blue circles) and simulated reflectance spectra (solid line) exhibit the same qualitative behavior. FDTD simulations of absorbed power within a nanopillar at a reflection (b) dip and (c) peak show enhanced absorption at resonance.